The Metallicity of the Local IGM from the HST/STIS Spectrum of 3C273

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Abstract. We present a preliminary study of the metallicity of low-redshift Lyman alpha absorbers from the HST/STIS spectrum of 3C273. Using a pixel-based shift-and-coadd technique, we compare observations to carefully-constructed mock quasar spectra from a cosmological hydrodynamic simulation. We place an upper limit of $[\mathrm{C/H}]_\odot < -1.5$ at $> 90\%$ confidence using two Lyα absorbers with $N_{\mathrm{HI}} > 10^{14}\mathrm{cm}^{-2}$, from the fact that we see little absorption near the expected C IV positions, whereas the artificial spectra predict significant absorption. We assume a Haardt & Madau (quasar-based) ionizing background spectrum, but a softer spectrum results in a stronger constraint on the metallicity. With only two absorbers and various modeling uncertainties, it is too early to make a definitive determination of the diffuse IGM metallicity, but upcoming observations should improve constraints.

1 Introduction

Weak Lyman alpha (Lyα) absorbers that are now detectable in HST/STIS quasar spectra are predicted to arise in diffuse non-equilibrium large-scale structures, analogous to high-redshift forest absorbers [1]; this has been preliminarily confirmed by first comparisons of the statistical properties of Lyα absorbers with simulations [2]. At high redshift, absorbers with $N_{\mathrm{HI}} \approx 10^{14.5}\mathrm{cm}^{-2}$ are already enriched to a level of $[\mathrm{C/H}]_\odot \approx -2.5$ [3][4]. It is of great interest to study similar absorbers at low redshift, to determine the rate at which metals have been injected into the IGM since $z \sim 3$. The results have implications for understanding early galaxy formation, associated blowout, and winds.

To study absorbers equivalent to $N_{\mathrm{HI}} \approx 10^{14.5}\mathrm{cm}^{-2}$ at $z = 3$ requires one to examine absorbers with $N_{\mathrm{HI}} \approx 10^{13}\mathrm{cm}^{-2}$ at $z \approx 0$ [1]. Unfortunately, since the sensitivity of HST/STIS spectra are now only approaching Keck/HIRES and VLT/UVES, it will be very difficult to detect metals in these systems unless the present day metallicity is much higher. This appears unlikely, since the metallicity measured from archival HST/FOS spectra is $[\mathrm{C/H}]_\odot = -1.6$ for significantly stronger absorbers [5] (equivalent width $W_r = 0.45 - 0.75$Å, corresponding very roughly to $N_{\mathrm{HI}} > 10^{15}\mathrm{cm}^{-2}$), and simulations predict that

less dense gas (i.e. weaker absorbers) has lower metallicity [6]. A mitigating factor is that overdensities of ~ 10 at $z = 3$ correspond to overdensities of ~ 50 at $z = 0$ due to gravitational growth of perturbations.

So instead, here we use stronger absorbers ($N_{\rm HI} > 10^{14}{\rm cm}^{-2}$) to make a first attempt at constraining the local IGM metallicity from the HST/STIS spectrum of 3C273. The metallicity in these systems is expected to be $[{\rm C/H}]_\odot > -2.5$, since they are have overdensities $\approx 30 - 50$ [1], and have had significant time since $z \sim 3$ to be enriched further. We use CIV absorption to trace the metallicity, as it is expected to be the strongest metal line redwards of Lyα arising from diffuse IGM gas.

2 Data and Simulations

The observations of 3C273 are discussed by Heap et al. in these proceedings. They were taken using HST/STIS's E140M grating, yielding 3 km/s pixels with 2.2 pixels per resolution element. The average S/N was 13 per pixel in the CIV region for 3C273, with a CIV redshift coverage of $\Delta z = 0.097$.

We compare to mock 3C273 quasar spectra drawn from a cosmological hydrodynamic simulation [2]. To model metal absorption, we add a uniform metallicity to the gas, and compute the CIV absorption using CLOUDY, taking the local density and temperature of gas from the simulation [4] and assuming an ionizing background predicted from quasars [7] (hereafter HM), with its amplitude set by matching the HI column density distribution amplitude [2].

3C273 has some fortunate advantages for the study of metal absorption. In addition to being at a redshift ($z_{\rm em} = 0.155$) that provides good coverage for both Lyα and CIV, and being the brightest nearby quasar, it also has two (apparently intergalactic) Lyα absorbers wih $N_{\rm HI} > 10^{14}{\rm cm}^{-2}$, where we would expect less than one [2]. There is a strong Virgo absorber ($N_{\rm HI} = 10^{15.8}{\rm cm}^{-2}$) in this spectrum that we do not consider, because it shows many low ions that suggest it is not arising in intergalactic gas.

3 Results

There are no intergalactic CIV absorbers detected as individual lines in the spectrum of 3C273. Thus we must rely on stacking techniques to improve our sensitivity. It has been noted that stacking suffers from the caveat that CIV and Lyα absorbers can be offset by ~ 20 km/s or more, so a coadded CIV "feature" will appear broadened [8]. This can result in an inaccurate estimate of the CIV/HI ratio if not interpreted correctly. The reason for this offset is that the ionization conditions of CIV and HI do not exactly match, so when one probes through a filament, the maximum HI absorption will not necessarily be coincident with that of CIV. The simulations used here reproduce this effect, since the ionization structure is computed locally across each absorbing structure. Thus it is important to use simulations to interpret stacked spectra.

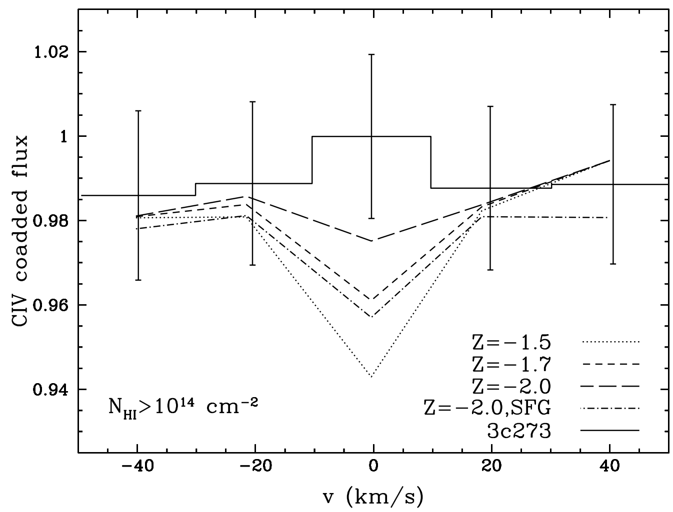

Figure 1: Pixel-by-pixel coaddition within ± 40 km/s centered on Lyα absorbers with $N_{\rm HI} > 10^{14}{\rm cm}^{-2}$. Histogram shows result from 3C273, with other lines show results from artificial spectra with uniform metallicity added as indicated.

Our procedure is as follows: We identify each Lyα absorber with $N_{\rm HI} > 10^{14}{\rm cm}^{-2}$; 3C273 has two such Ly$\alpha$ absorbers at $\lambda = 1219.77, 1296.57$Å, having column densities of $10^{14.2}, 10^{14.07}{\rm cm}^{-2}$. Our AutoVP-fit column densities for these absorbers are consistent with results from a FUSE+GHRS analysis [10], which uses Lyβ absorption to constrain the column density. We examine the pixels at associated CIV(1548.2Å) within ± 40 km/s of the Lyα absorber velocity, and bin those flux decrements (constrained by twice the doublet position's flux decrement) in velocity space.

The solid line in Figure 1 shows the result of this procedure for 3C273, while other lines show the result of varying the metallicity in the artificial spectra from $[{\rm C/H}]_\odot = -1.5 \rightarrow -2.0$. The two absorbers in 3C273 are consistent with no absorption at the expected CIV position. $[{\rm C/H}]_\odot = -1.5$ is ruled out at $> 2\sigma$ level. Also, a K-S test of the (pre-binned) flux distribution finds a 0.2% probability that the simulated and observed fluxes are drawn from the same underlying distribution. The observed and simulated samples are formally consistent for $[{\rm C/H}]_\odot = -2.0$, and discrepant by $\approx 1.5\sigma$ for $[{\rm C/H}]_\odot = -1.7$. Thus we quote a 2σ upper limit of $[{\rm C/H}]_\odot < -1.5$ for these two absorbers.

The shape and amplitude of the ionizing flux is a large uncertainty in our modeling. The amplitude is reasonably well-constrained at the Lyman limit [2], but altering the shape can change the CIV photoionization rate significantly. We have assumed a J_ν shape taken from quasars by HM, but star forming galaxies may provide a significant contribution to the local flux [9]. In order

to test this, we generate a "toy" star forming galaxy (SFG) spectrum, where we simply multiply the HM spectrum by ν^{-2}, keeping $\Gamma_{\rm HI}$ fixed. The result for this ionizing spectrum is shown as the dot-dashed line in Figure 1 for $[{\rm C/H}]_\odot = -2.0$. Qualitatively, softening the spectrum has the effect of increasing CIV absorption and thereby strengthening our metallicity constraint.

While there are only two absorber in this spectrum with $N_{\rm HI} > 10^{14}{\rm cm}^{-2}$, we could attempt to lower the column density threshold to include more lines and improve statistics. However, even reducing to $N_{\rm HI} = 10^{13.5}{\rm cm}^{-2}$ significantly weakens the result, because the simulations predict many more pixels with little or no CIV absorption. Also, note that if there was chance coincident absorption near the CIV position, it would only strengthen our constraint.

4 Summary and Discussion

We have placed a preliminary upper limit on the metallicity in filamentary large-scale structure (overdensity $\approx 30 - 50$) using two absorbers with $N_{\rm HI} > 10^{14}{\rm cm}^{-2}$ in the HST/STIS spectrum of 3C273. Using cosmological hydrodynamic simulations to calibrate the pixel-based stacking technique, we find $[{\rm C/H}]_\odot < -1.5$ at greater than 90% confidence level, with some sensitivity to the assumed ionizing background shape. Or result could be compromised if (i) our simulations are incorrectly modeling the density-temperature structure of the IGM, (ii) the ionizing background is significantly *harder* than that from quasars, or (iii) these two absorbers have anomalously low metallicities. While none seem *a priori* likely, more data and model comparisons are needed.

If our result holds up with upcoming larger and more sensitive samples, it would suggest that the metallicity of the diffuse IGM has increased by less a factor of 10 since $z \sim 3$ (90% of the age of the Universe). This favors a scenario where the enrichment of the IGM occured predominantly at $z \gg 3$, a fact that may constrain wind and ejection models from high redshift galaxies (e.g. Ferrara, these proceedings), and help interpret OVI observations in the local IGM (Tripp et al., these proceedings).

References

[1] Davé, R., Hernquist, L., Katz, N., & Weinberg, D. H. 1999, ApJ , 511, 521
[2] Davé, R. & Tripp, T. M. 2001, ApJ , 553, 528
[3] Songaila, A. & Cowie, L. L. 1996, AJ , 112, 335
[4] Davé, R., et al. 1998, ApJ , 509, 661
[5] Barlow, T. & Tytler, D. A. 1998, AJ , 115, 1725
[6] Cen, R. & Ostriker, J. P. 1999, ApJ , 519, 441L
[7] Haardt, F. & Madau, P. 1996, ApJ , 461, 20
[8] Ellison, S. L., Songaila, A., Schaye, J., & Pettini, M., AJ , 120, 1175
[9] Shull, J. M., et al. 1999, AJ , 118, 1450
[10] Sembach, et al. 2001, ApJ , accepted, astro-ph/0108047